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TITLE: The RCM2 10 Bars Test Case. Combustion of Cryogenic Propellant at 10 Bars Using the CPS Code

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The RCM2 10 bars test case

Combustion of cryogenic propellant at 10 bars using the CPS code

2nd International Workshop on Rocket Combustion Modelling
Lampoldshausen March 25-27, 2001

Presented by Laurent Lequette form Bertin Technologies

1. The introduction
2. The objectives and the approach
3. The main results
4. The numerical and the physical models
5. The results presentation
6. The conclusion

2nd RCM Workshop : RCM2 10 bars test case
The introduction

- Bertin Technologies
  - technological services provider and consultancy
  - French private company
  - staff : 250 employees
- The SIMA team
  - working in Information Systems and Advanced Modelling
  - has been involved in CFD modelling for more than 15 years and has developed several CFD tools like CALIFE, THESEE and now CPS
- This work has been founded by CNES

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The introduction

The CPS code

- new generation CFD code
  - unstructured meshes (3D)
  - Roe and Toumi formulation for Euler fluxes
  - explicit and implicit schemes (for steady and for unsteady flows)
  - turbulence models (Jones-Launder, Coakley, RNG, subgrid, ...)
  - Eulerian two phases model
  - Lagrangian two phases model (LASVEGAS)
    - atomisation and coalescence
    - arbitrary time step
    - high volumic rates
  - Combustion models (Arrhenius, TECK, flame surface)

- developed by Bertin Technologies and SNPE Group together
  - benefits from earlier developments of both companies

- a commercial version is being launched
  - we are looking for pilot customers

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The objectives and the approach

- The objectives
  - To asses the most recent developments of CPS for cryogenic applications
  - To retrieve guidelines for future developments of CPS
    - numerical point of view
    - physical models

- The approach
  - Lagrangian two phases models (LASVEGAS model)
  - Use of CPS from an engineer point of view
    - Use of standard options only
    - No special treatment for the injection area
    - No parameters tuning
    - Start from zero with all the models activated
  - Comparison of normal Lox injection (3 m/s) and accelerated (10 m/s) as recommended for the WS

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The main results

- No major numerical difficulty using the explicit Roe-Toumi scheme, but
  - it has not been possible to inject inside the Lox injector
  - the implicit scheme is not robust enough for such an application
- The results are sensitive to the laminar binary diffusion coefficients values
- The results are not very sensitive to the use of the Rosin-Ramler distribution instead of constant diameters
- Some improvements of the injection area have to be done
  - it is not clear where the added Lox quantity of movements comes from, for the 10 m/s injection case
- The maximum temperature is around 2500 K and the pressure close to 10 bars
  - it seems to be close from experimental values

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The numerical and the physical models

- Numerical models and parameters
  - second order Roe-Toumi explit scheme
  - CFL 0.5
  - steady state optimisation (local time steps for gas)
  - unsteady approach for droplets

- Physical models and parameters
  - Mixing of perfect gas (H_2, O_2 and H_2O)
  - varying C_p and C_v
  - laminar viscosities function of the temperature
  - Coakley (q,ω) turbulence model
  - LASVEGAS Lagrangian two phases model
  - TECK combustion model (improved EBU-Arrhenius model)

- Mesh
  - 3880 elements
  - Whole domain including the nozzle

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The numerical and the physical models

- GH2 Inlet boundary conditions : mass flow rate and total temperature fixed
  - $Q = 267.96$ kg m^{-2} s^{-1} $\quad$ $Tt = 290.56$ K
  - $k = 380$ m^{2} s^{-2} $\quad$ $\omega = 800$ s^{-1}
- Outlet boundary conditions : fixed pressure
  - $Ps = 39.7\ 10^{5}$ Pa $\quad$ $Ts = 293.$ K (for reentrant flow only)
  - $k = 10$ m^{2} s^{-2} $\quad$ $\omega = 100$ s^{-1} (for reentrant flow only)
- Lox Injector
  - $T = 85$ K $\quad$ $Q = 2546.5$ kg m^{-2} s^{-1} $\quad$ $v = 2.18$ m/s or 10 m/s
  - Rosin-Ramler diameters distribution
  - equivalent to a wall for the gas
- Walls
  - adiabatic
  - turbulent law of the wall
  - tangential film for impacting droplets

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The numerical and the physical models

- Chemistry parameters for TECK model
  - Activation temperature 2000 K
  - Pre-exponential coefficient 10^{12}
  - H2 and O2 partial orders 1.
  - Threshold temperature 300 K

- Binary diffusion coefficients
  - $D_{A,B} = 1.013\ 10^{-7}\ T^{-1.75}\ (1/M_A + 1/M_B)^{1/2}\ /\ P\ /\ (V_A^{1/3} + V_B^{1/3})$
    - with P defined in bars, M in g/mole
    - $V_{O2} = 16.6$ $V_{H2} = 7.07$ $V_{H2O} = 12.7$

- Thermal conductivities
  - function of temperature

- Initial conditions
  - $Ps = 10^5$ Pa $Ts = 300$ K $v = 100\ m\ s^{-1}$
  - YH2=1. $K = 200\ m^2\ s^{-2}$ ω=100 ms-1

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The results

- Some results may not be thoroughly converged but all of them are converged in the combustion area

- As a single reaction model was used, OH fractions cannot be presented, but the production rate for temperature can be used to visualise the flame location

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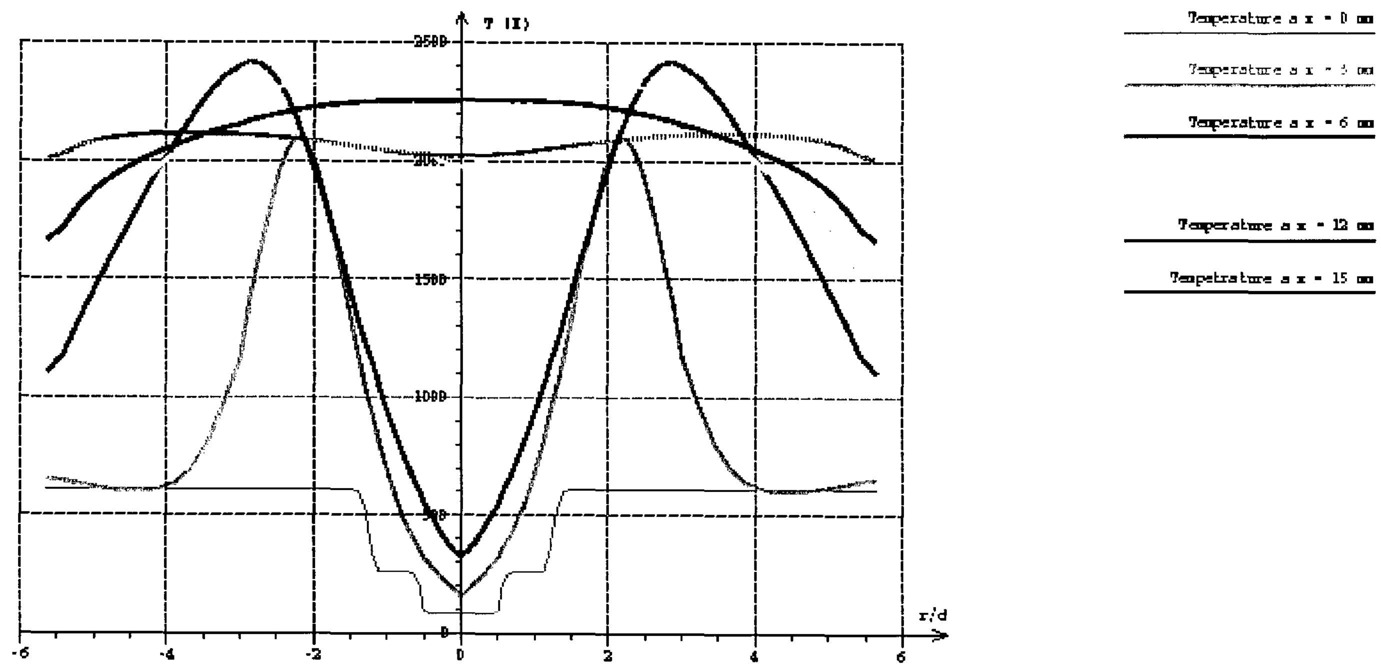
The results

Temperature
RCM2 2D : monodisperse case
droplet diametre = 110 microns

n : 270993
mini: 85.371
maxi: 2418.7



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The results

5

Volumic rate for the polydispersed phase
RCM2 2D : monodisperse case
droplet diametre = 110 microns

n : 270993
mini: 0.0000
maxi: 4.7030

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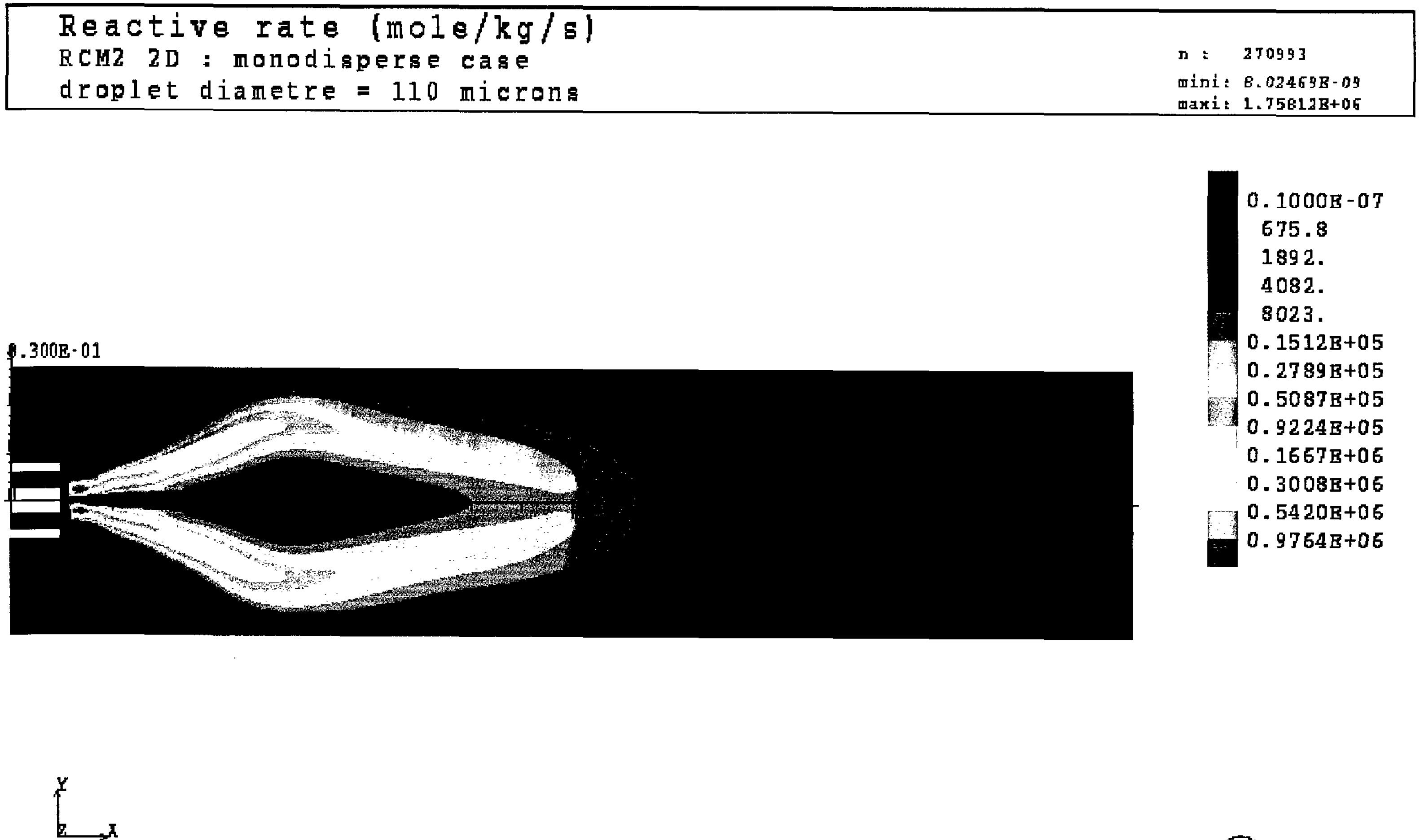
The results



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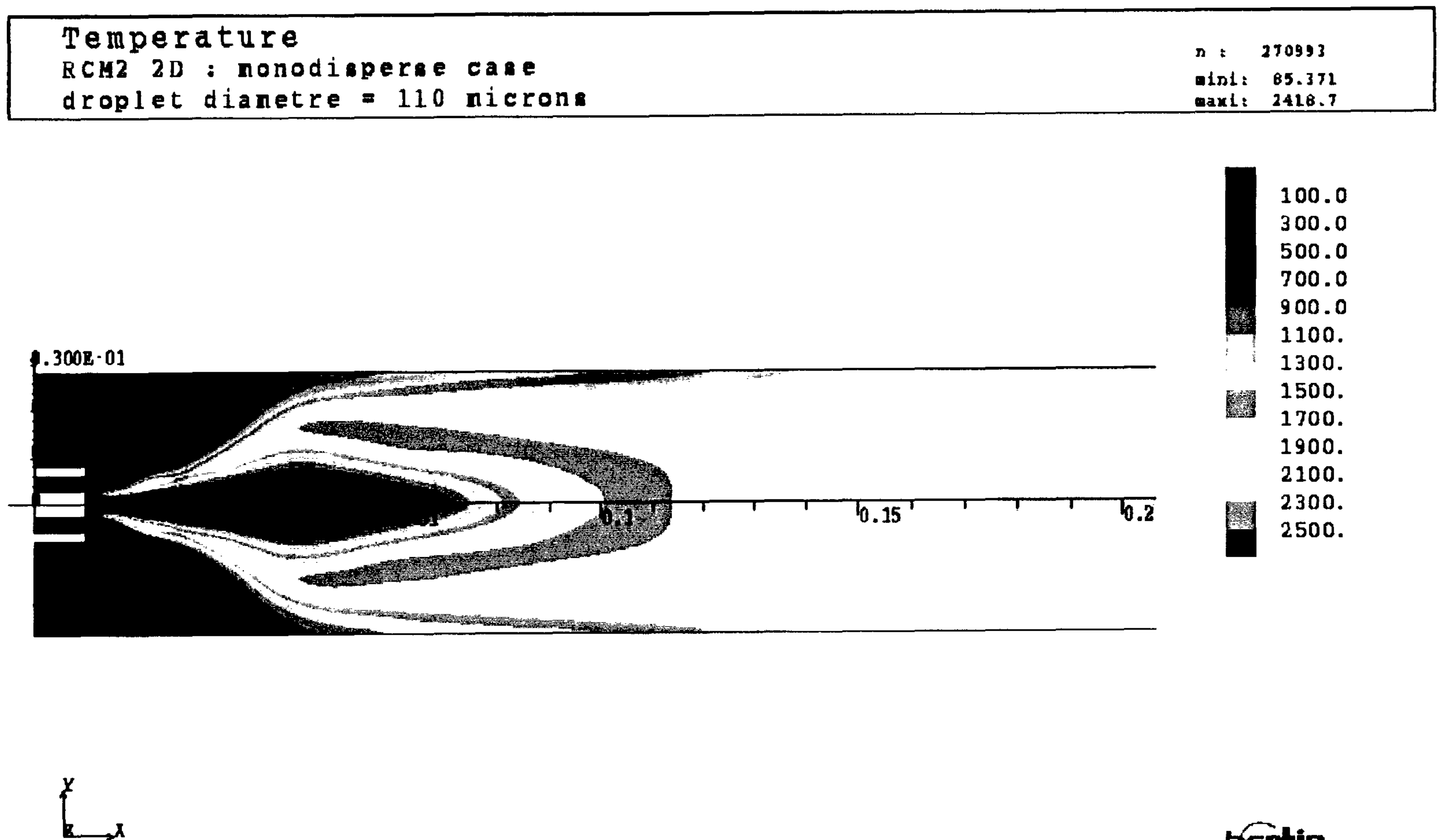
The results



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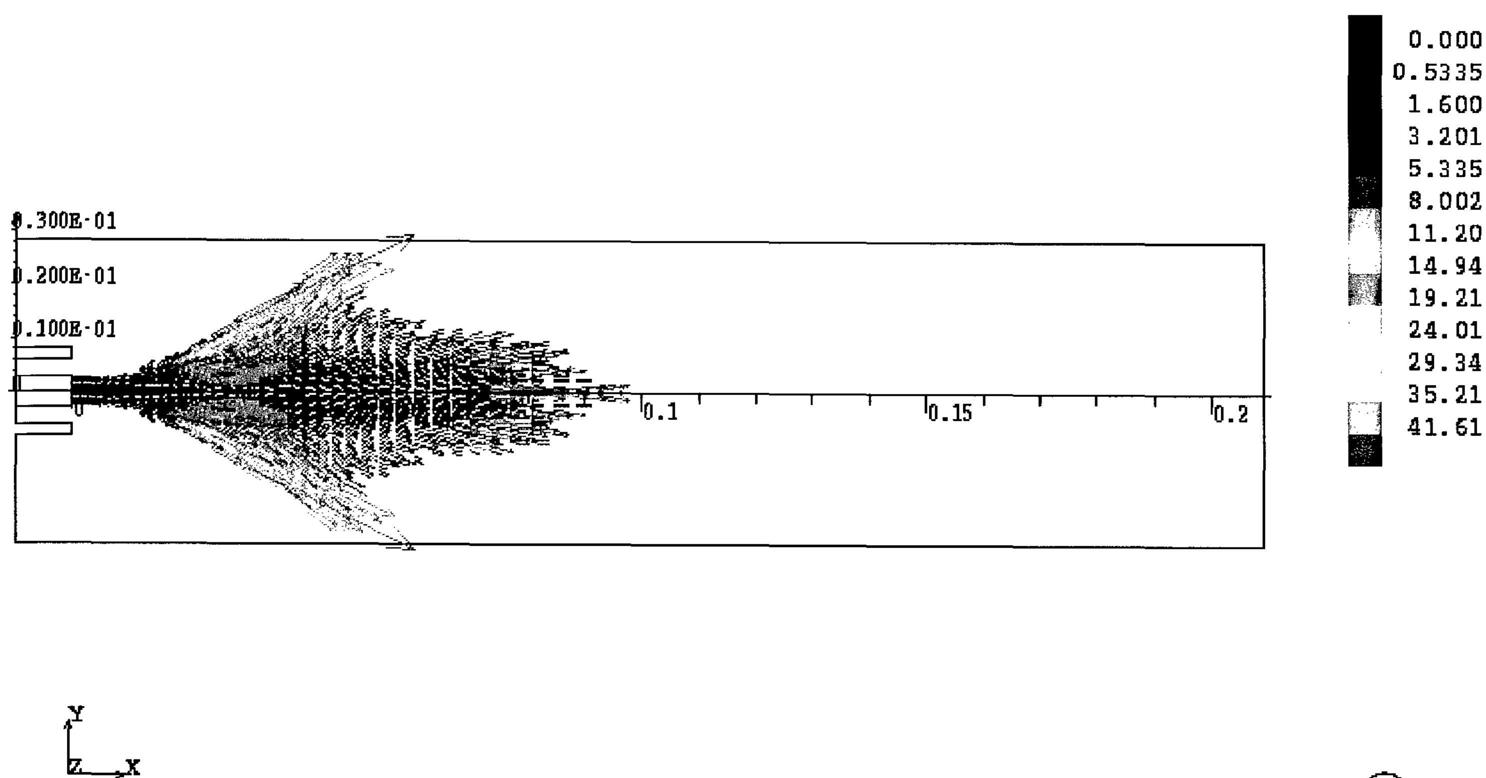
The results

Velocity vectors of the dispersed phase
RCM2 2D : monodisperse case
droplet diameter = 110 microns

n : 270993
mini: 0.0000
maxi: 41.611



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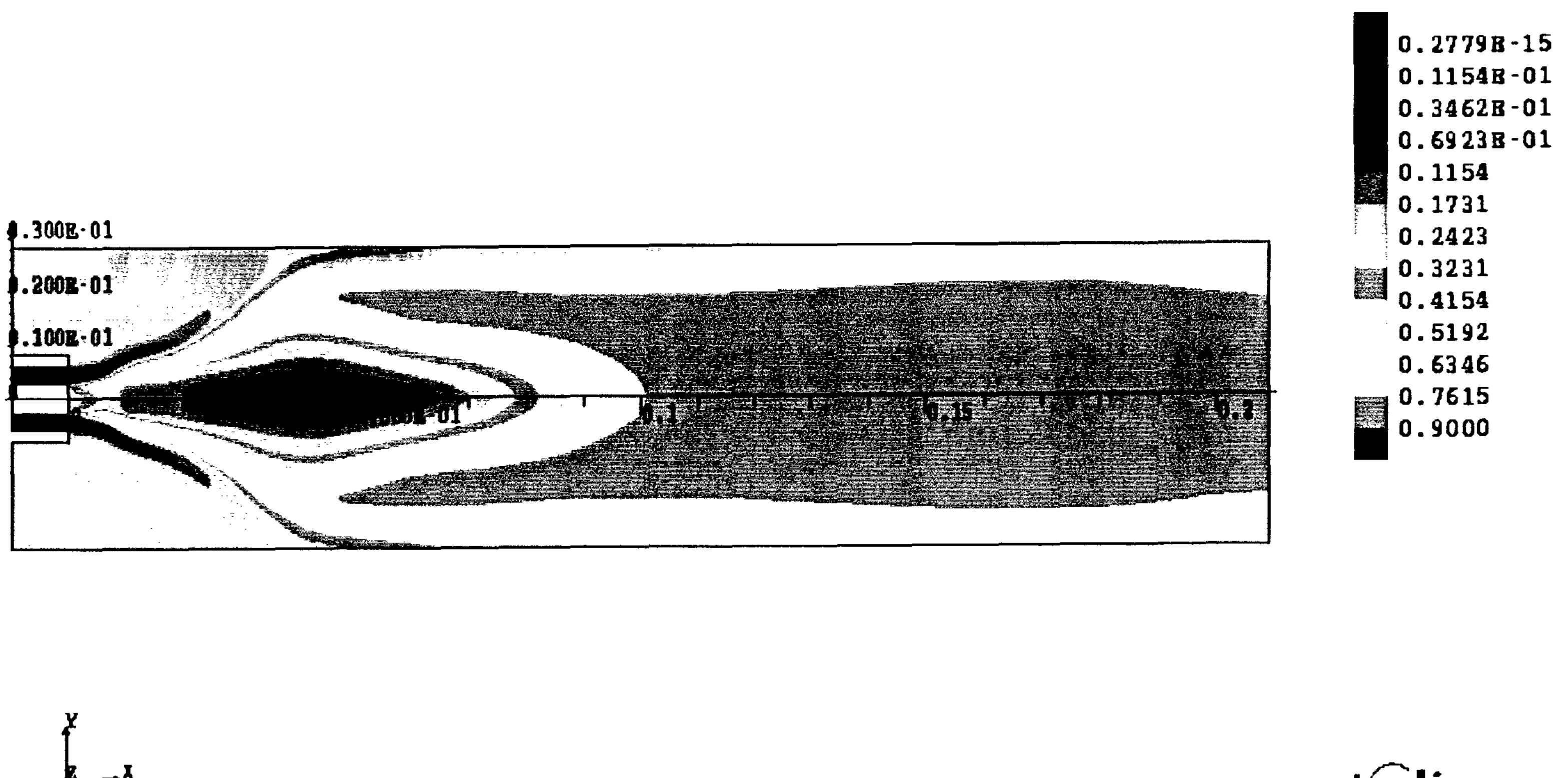
The results

Massic fraction of H2O
RCM2 2D : monodisperse case
droplet diametre = 110 microns

n : 270993
mini: 2.77865E-16
maxi: 0.87504



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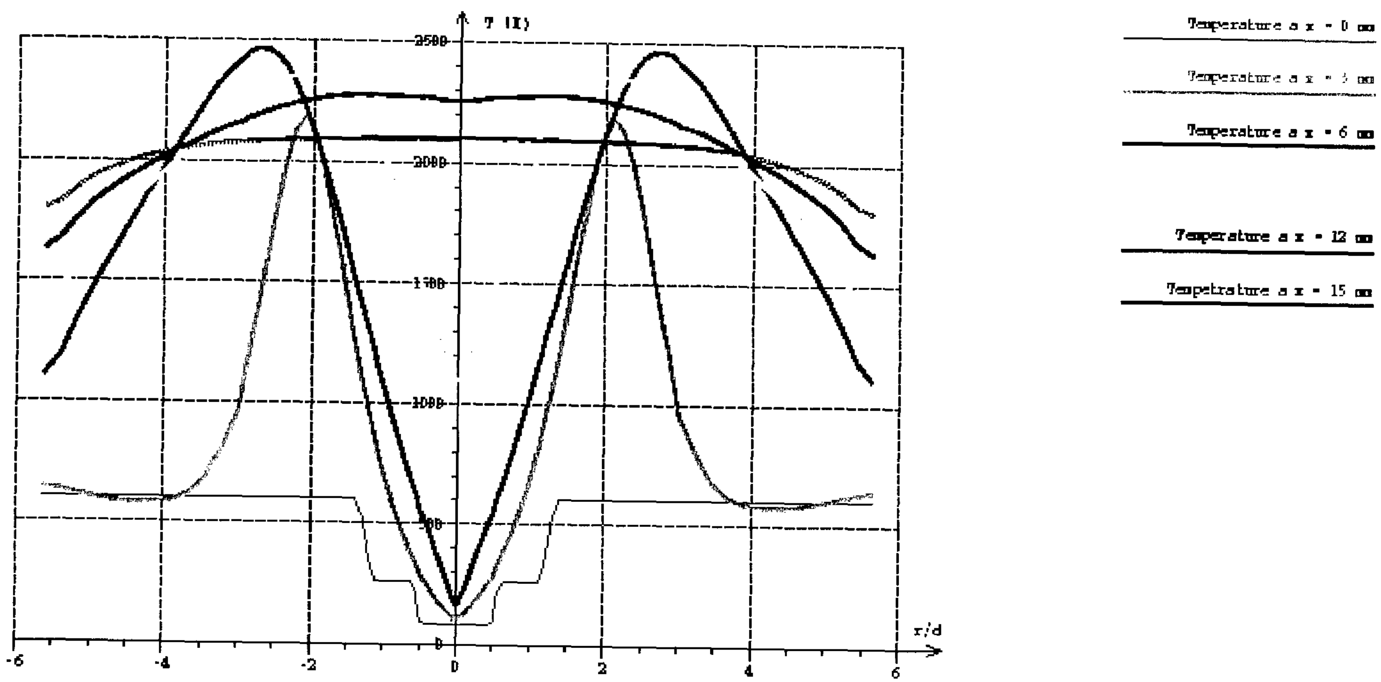
The results

Temperature
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 83.648
maxi: 2483.5



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The results

Volumic rate for the polydispersed phase
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 0.0000
maxi: 4.3172

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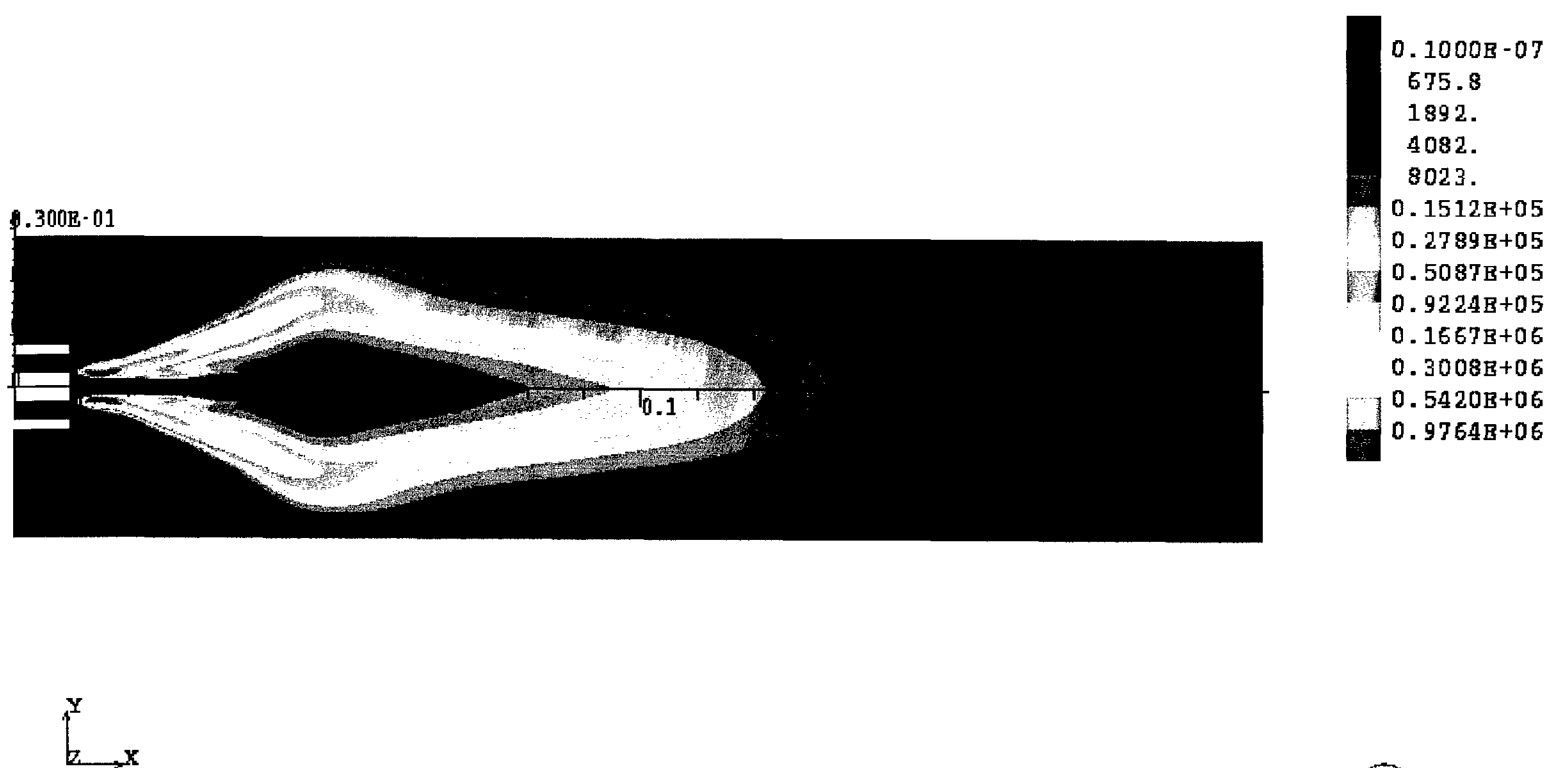
The results

Reactive rate (mole/kg/s)
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution

n : 134004
mini: 8.02469E-09
maxi: 2.69424E+06



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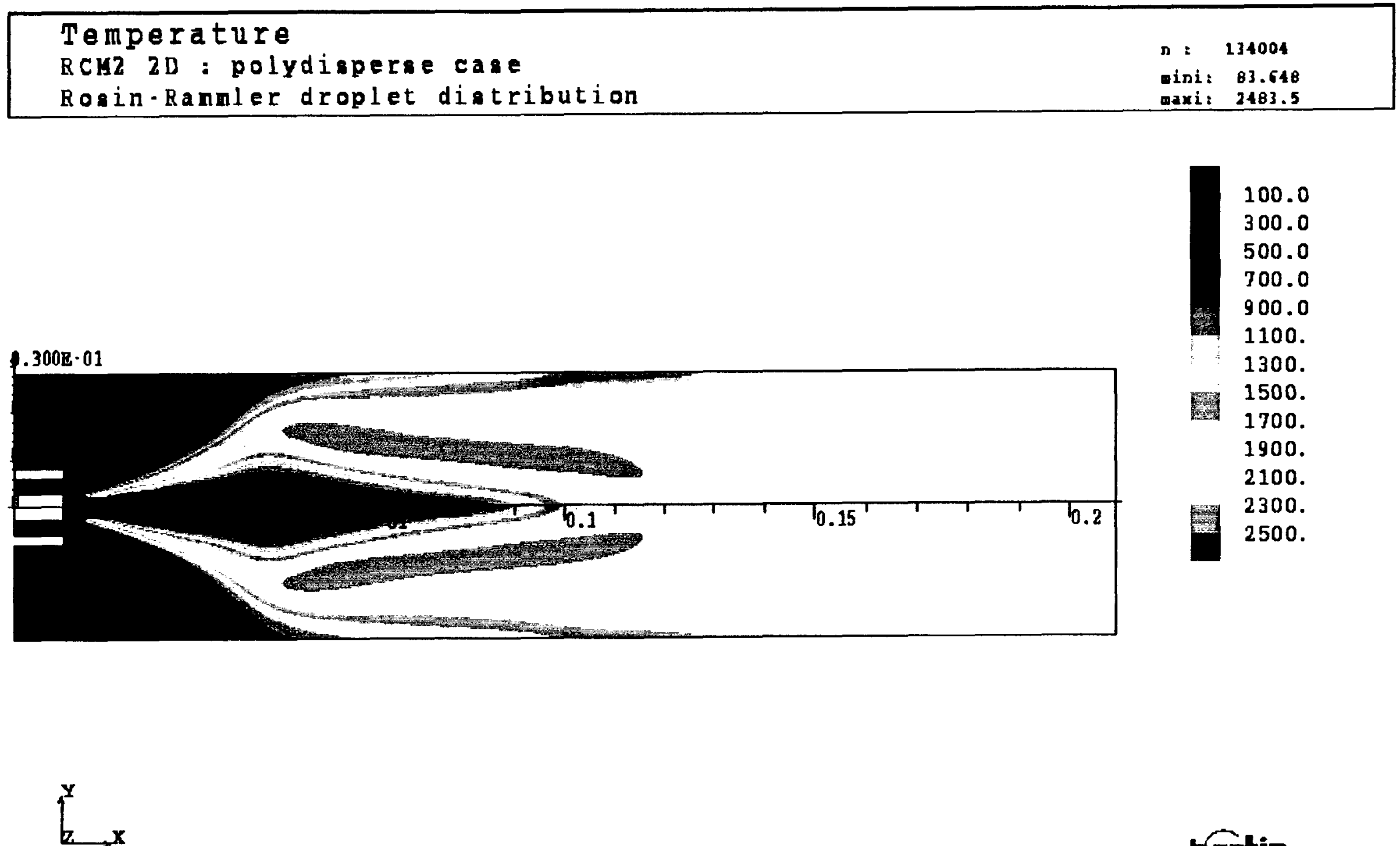
The results



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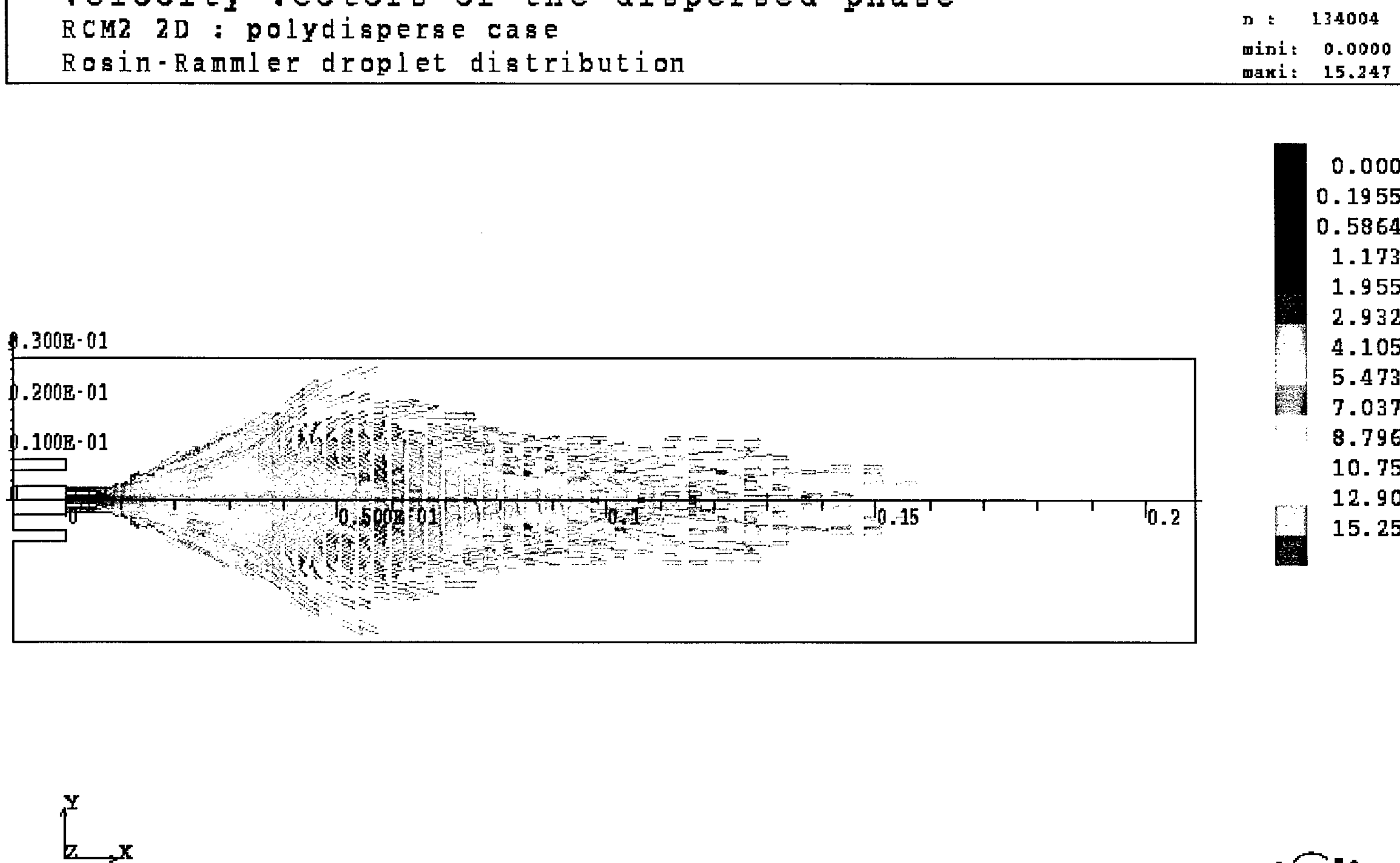
The results

Velocity vectors of the dispersed phase
RCM2 2D : polydisperse case
Rosin-Rammler droplet distribution



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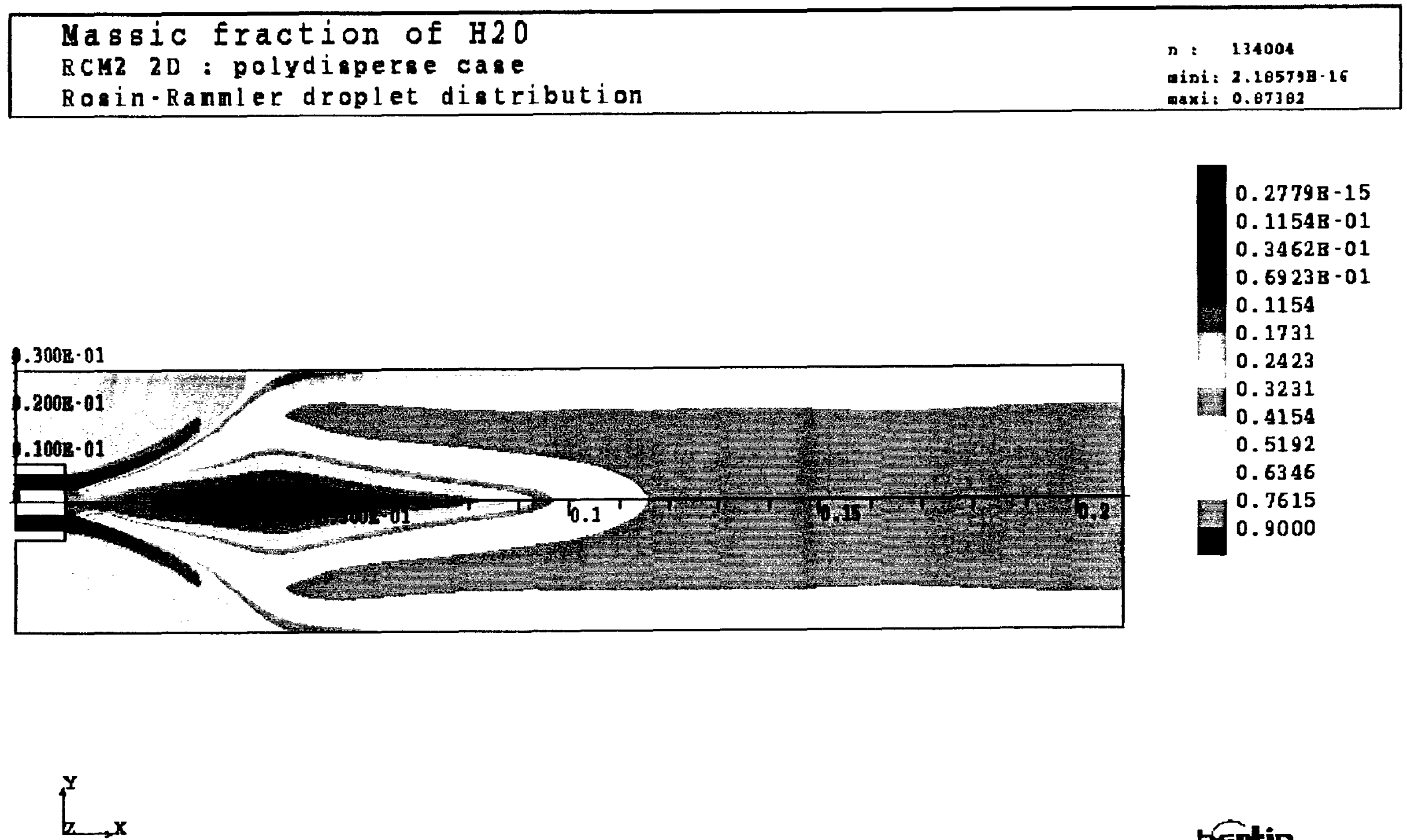
The results



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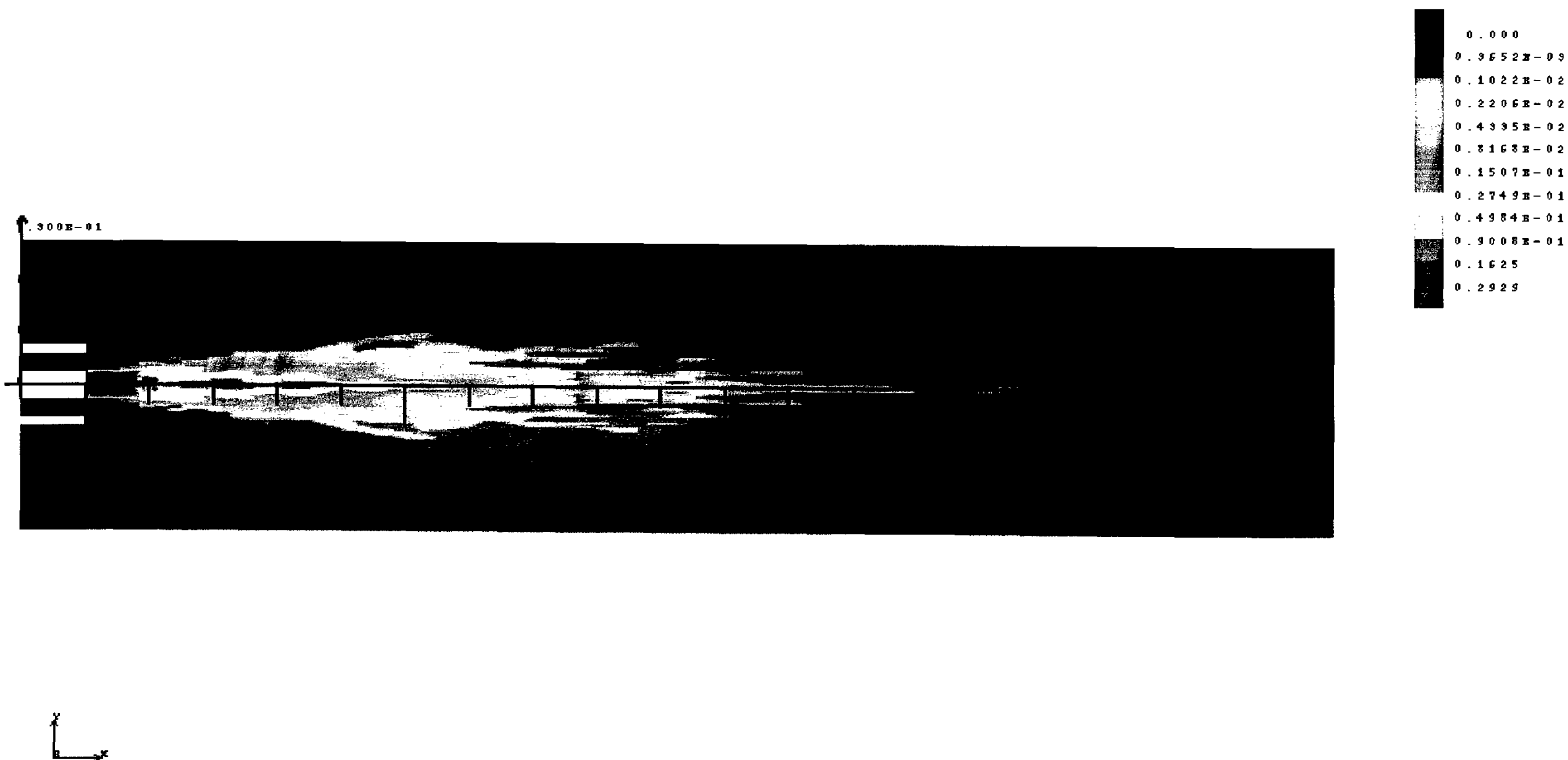
The results

Volumic rate for the polydispersed phase   t : 0.0000
Test case   Rosin Ramler V=10 m/s
mini: 0.0000
maxi: 0.41039



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The results

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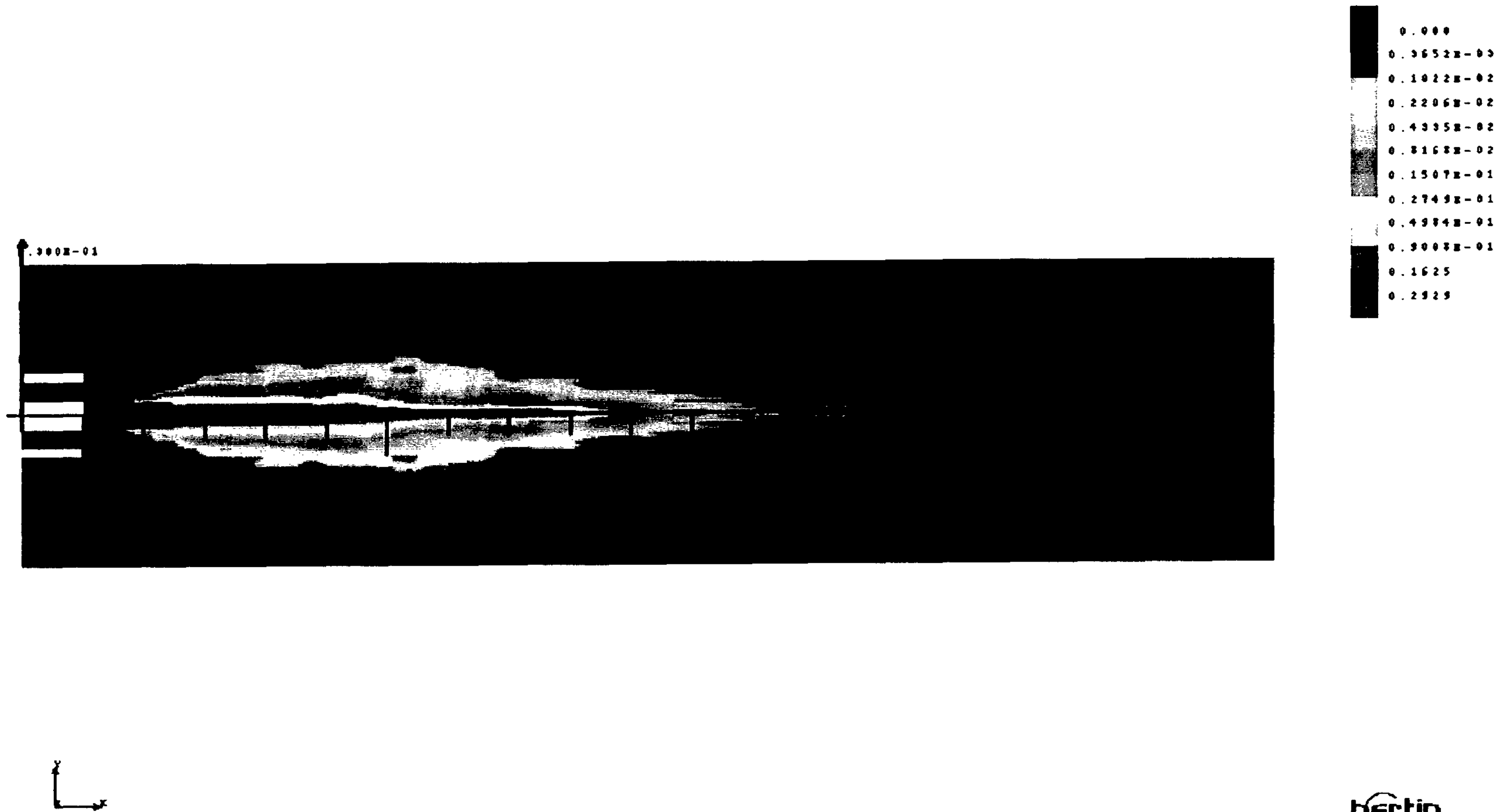
Volumic rate for the polydispersed phase
Test case Rosin Ramler V=3 m/s



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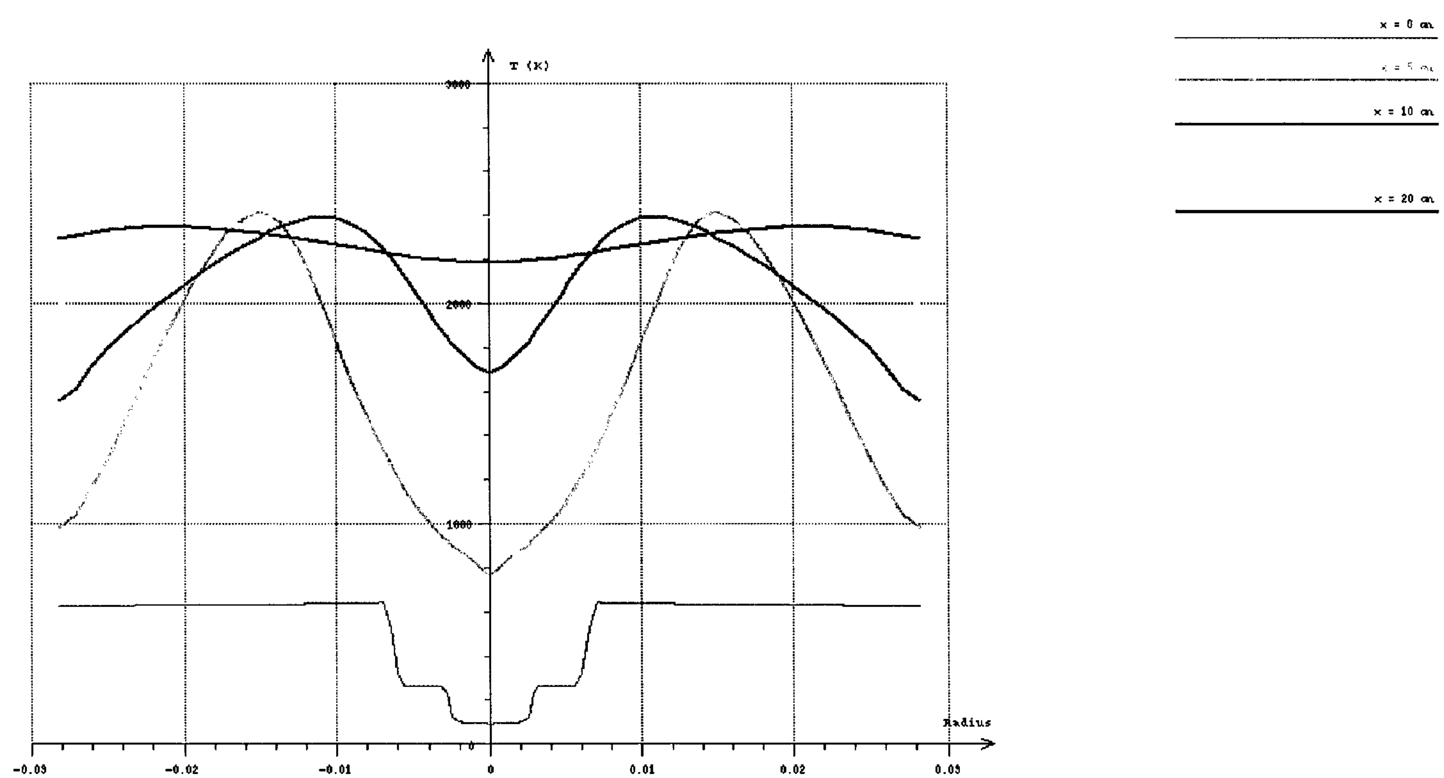
The results

Temperature
Test case Rosin Ramler V=10 m/s

t : 0.0000
mini: 91.325
maxi: 2459.5



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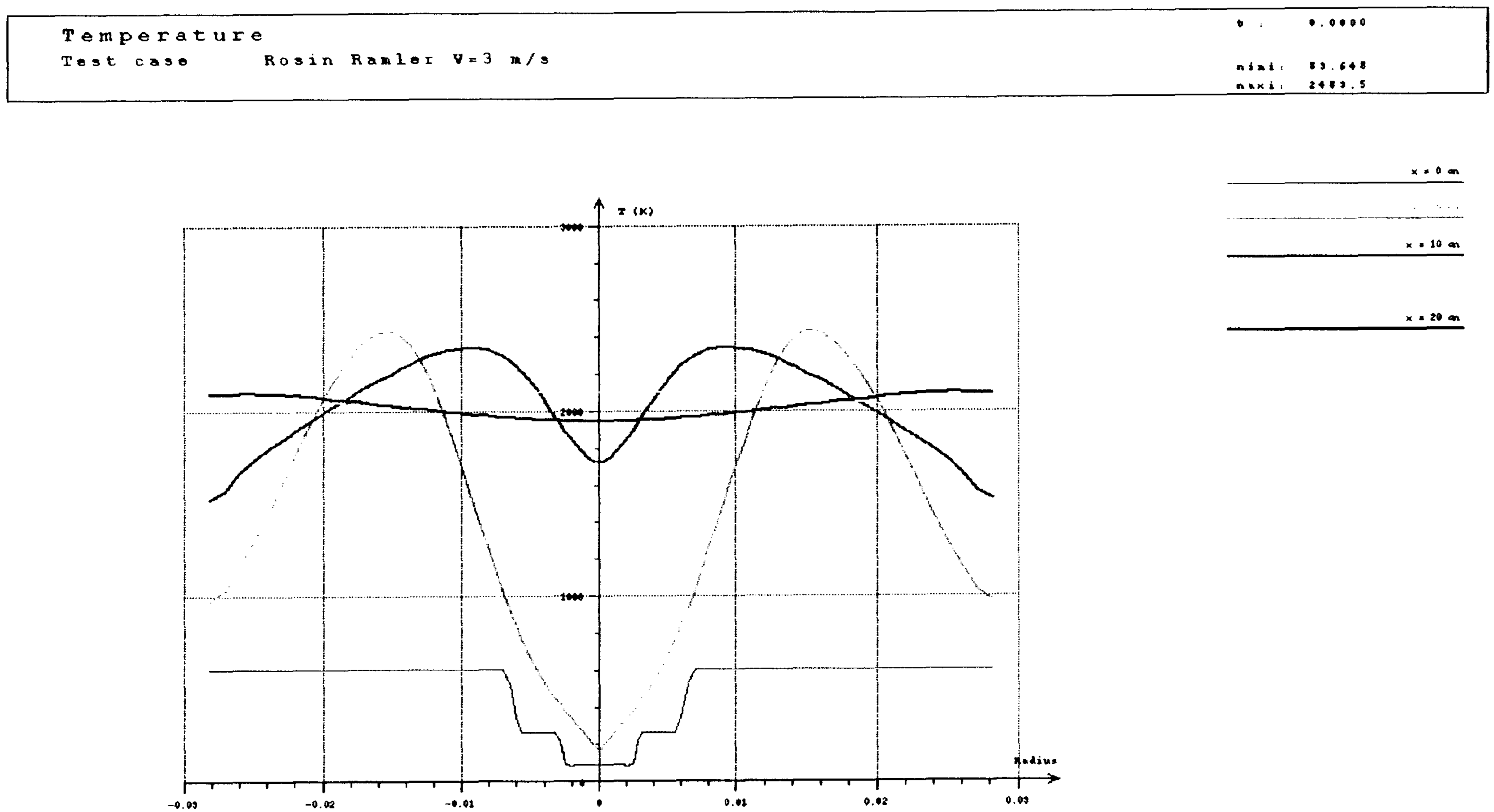
The results



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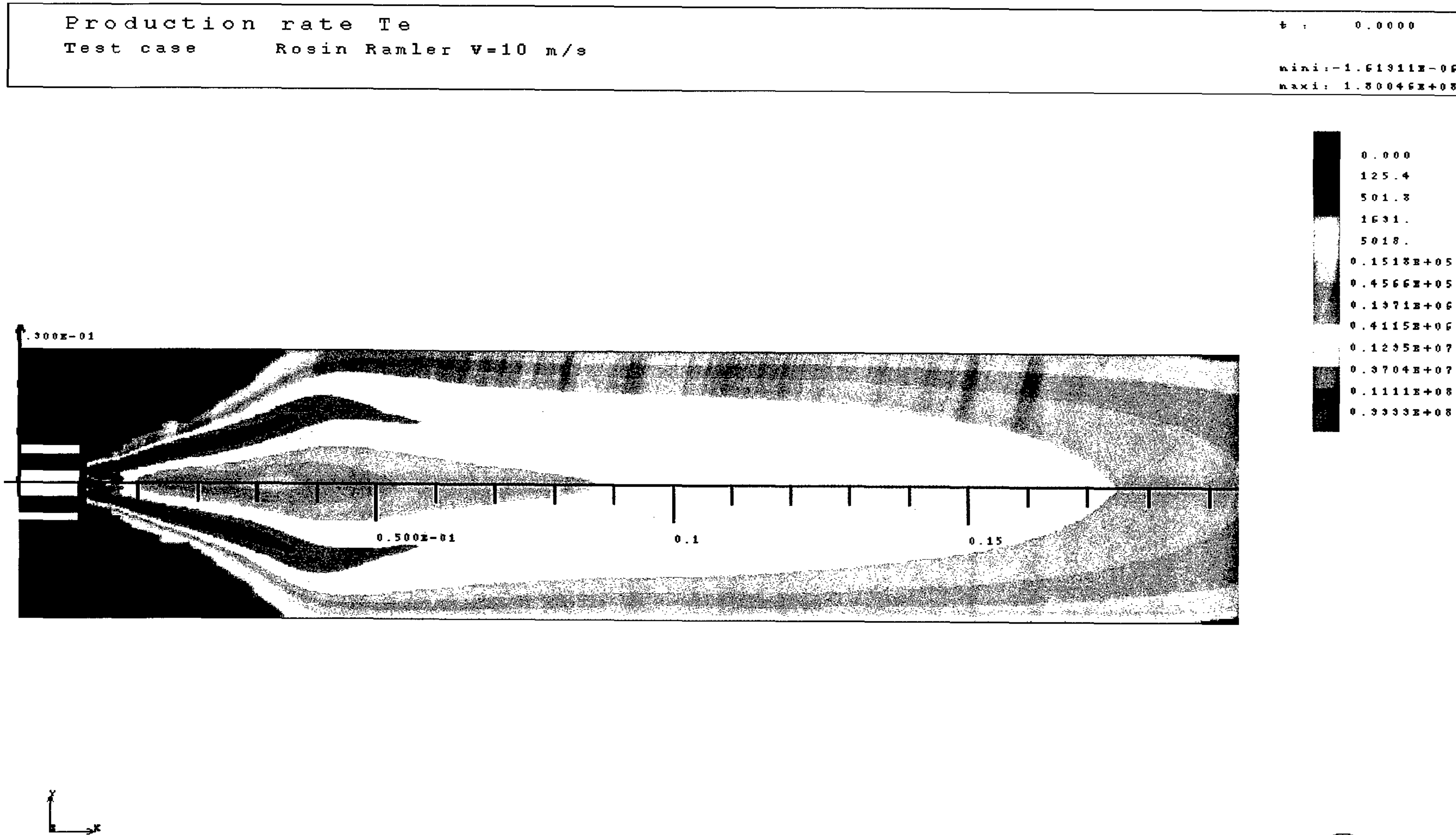
The results



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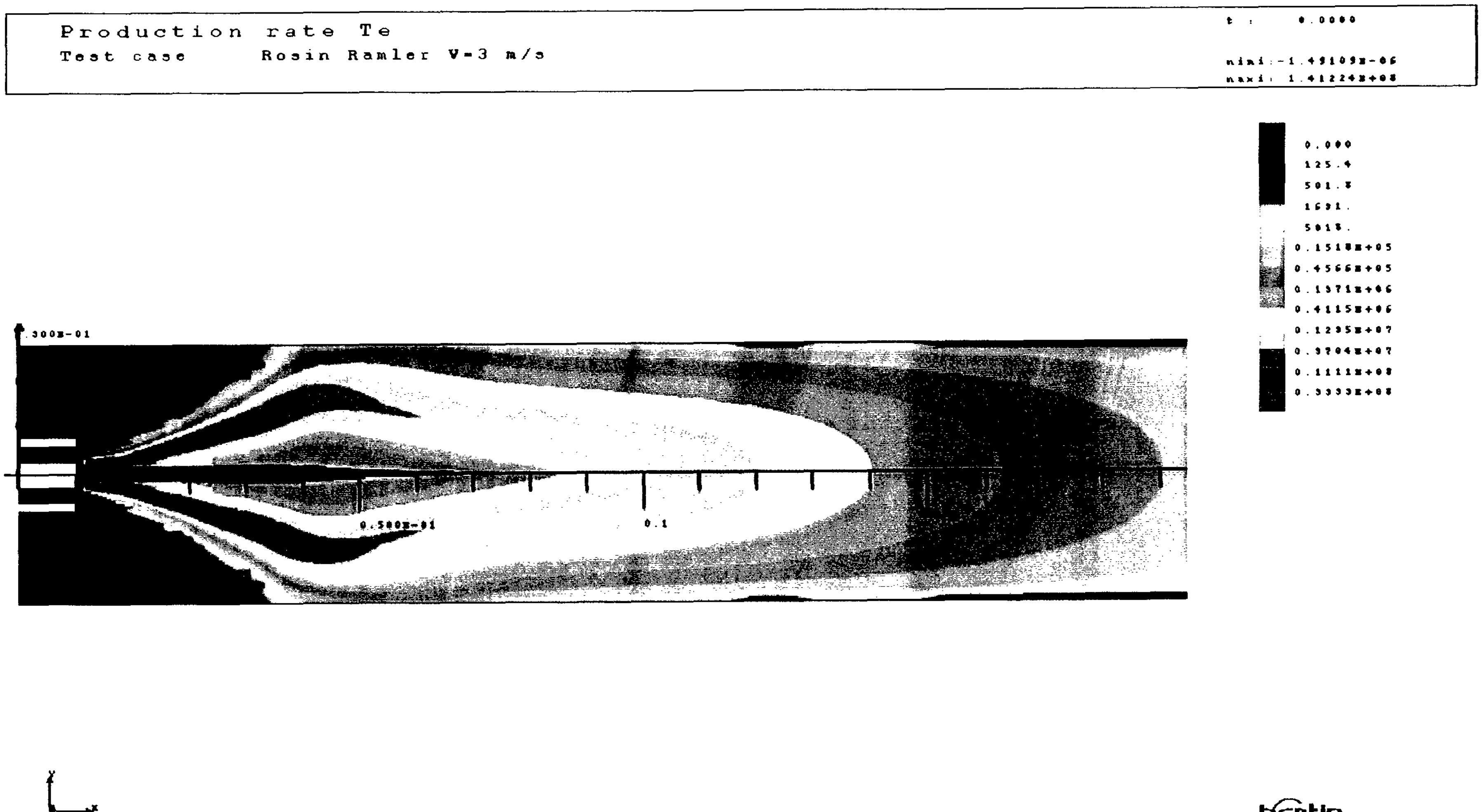
The results



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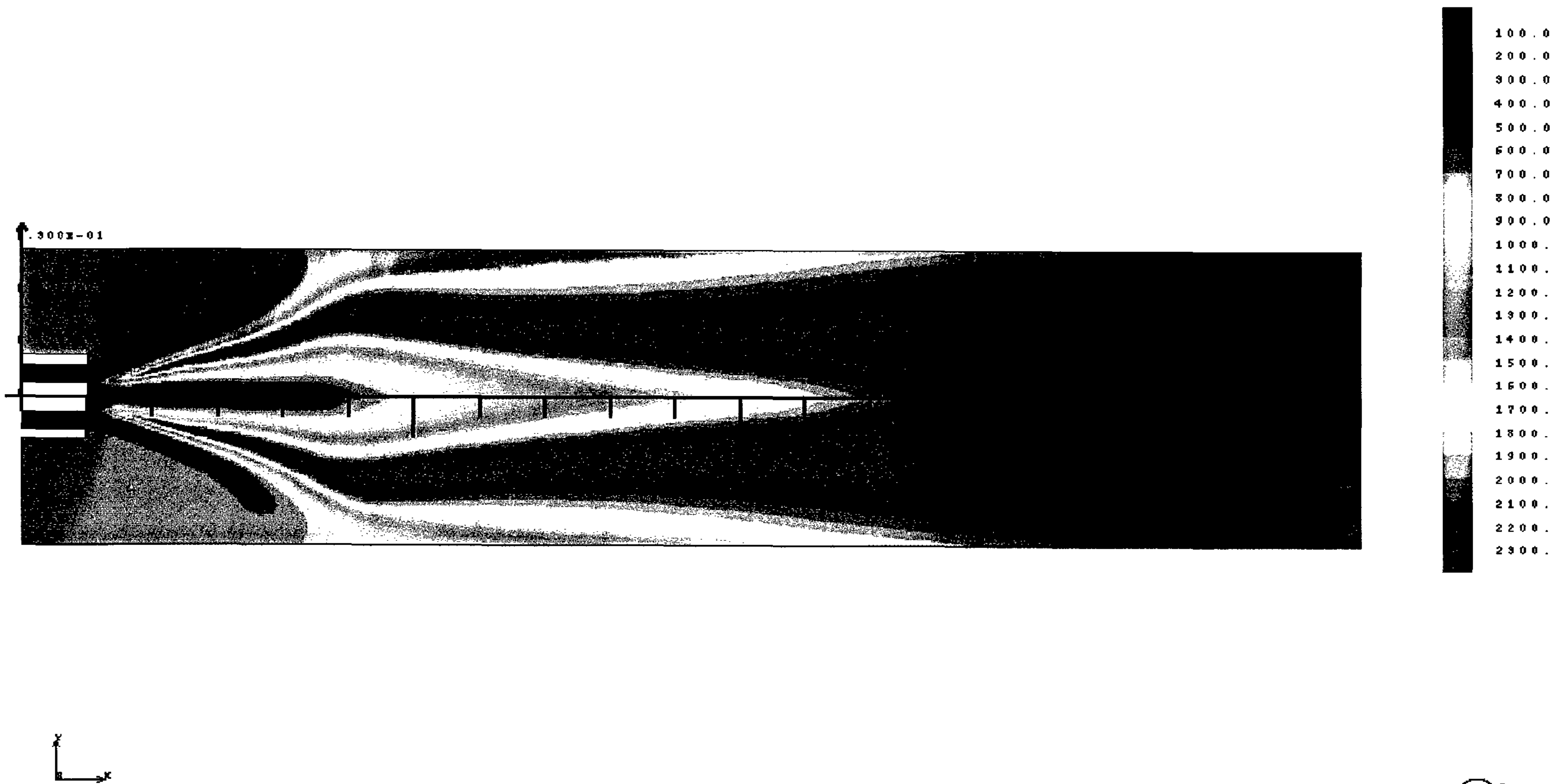
The results

Temperature
Test case   Rosin Ramler V=10 m/s

t : 0.0000
mini: 91.925
maxi: 2459.5



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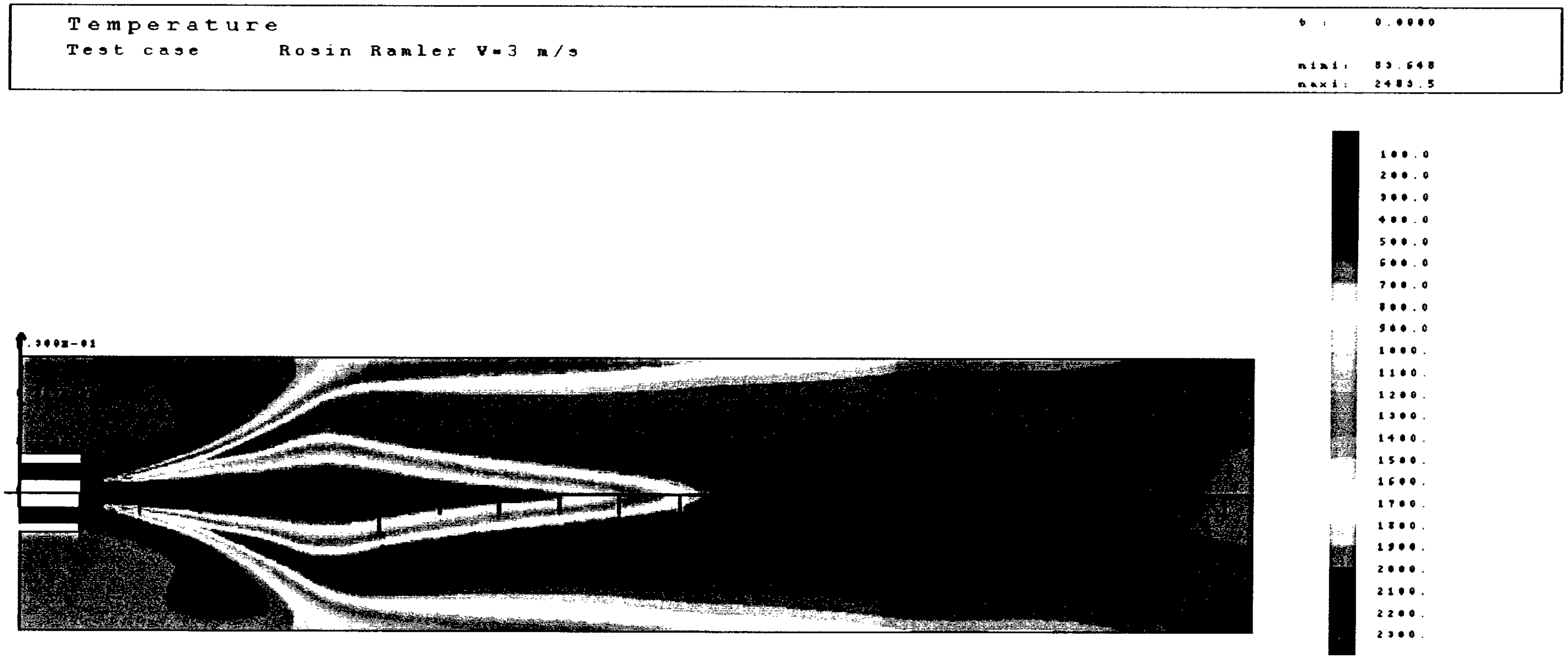
The results



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The conclusion

- The use of the most recent version of CPS has been quite straightforward
  - the recent developments to deal with high volumic rates areas appear to be quite robust and can still be enhanced with respect to evaporation
  - it would be be very easy to introduce some very large "droplets" as it seems it appears during experiments
- Further developments must be done to be able to use the implicit solver
  - this mandatory to decrease the CPU cost which is very high
- The comparison with experimental results will allow to asses the quite "rough" injection strategy
  - at least it is conservative
- Good thermodynamic properties is essential for a good evaporation model